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Winter energy behaviour in multi-family block buildings in a temperate-cold climate in Argentina

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ABSTRACT

This paper analyzes the thermal and energy behaviour of apartments in three-story block buildings located along a NE-SW axis (azimuth = 120°) in a temperate-cold climate (latitude: 36°57′; longitude: 64°27′) in the city of Santa Rosa, La Pampa, central Argentina. Four apartments had been monitored during May and June 2009. Three of them are located in Block 126. Two of these apartments face South: 15 and 23 on the SE end, ground and first floor, respectively; 18 faces N on the second floor. Finally apartment, 12 is located in Block 374, on the first floor, faces N and shows a carpentry-closed balcony. The purpose of this work is – to study the evolution of the indoor temperature in each apartment; to analyze energy consumption and comfort conditions; to study energy potential and energy intervention in order to reduce energy consumption; to analyze bioclimatic alternatives feasibility and the possibility to extrapolate results to all blocks. On the basis of the analysis of natural gas historical consumption records, results showed that regarding heating energy consumption during the period May–June, Apartment 12, facing N, with its only bedroom facing NW and its carpentry-closed, transparent glass balcony, presented a mean temperature of 21.2 °C, using a halogen heater for 6 h/day between 9 pm and 2 am (0.16 kWh/day/m^2). Apartment 15, on the SE end, first floor of the block consumed 22.5 kWh/day (0.43 kWh/day/m^2) (mean temperature = 22.2 °C). Apartment 23, located on the second and top floor (on top of Apartment 15) with higher energy loss, consumed 28 kWh/day (0.54 kWh/day/m^2) (mean temperature = 23.7 °C). Apartment 18, also on the second floor and facing N, located in the centre and with its only bedroom facing SE, consumed 18.8 kWh/day (0.48 kWh/day/m^2) (mean temperature = 22.3 °C). Apartment 23, with higher thermal loss through its envelope, but with heat transfer from the apartment located below, is the one that showed the highest level of consumption/m^2. Closing the balcony with carpentry produced an important reduction of energy consumption while reaching comfort conditions. The analysis of the experimental results allowed: (a) to determine through analysis of historical consumption of natural gas prior to the year 2009 that the owner lived under conditions of comfort, (b) to evaluate possible interventions in the building that would lead to saving heating energy. Thermal insulation of roof and envelope appears as the most feasible alternative whereas closing balconies constitute a very good design option in winter.

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1. Introduction

We live in an increasingly urban world, where more than half of humanity lives in urban areas [1]. By the year 2025, about 65% of the world's population is expected to live in urban areas [2]. Urbanization promotes rapid social and economic development, but at the same time, leads to many problems, such as concentration of the population, traffic jams, housing shortage, heat island effects, noise, air and water pollution, etc. [3,4]. People are increasingly realizing the importance of a sustainable urban environment that will mitigate or eliminate the negative effects of urbanization [5]. Urban areas drive much of the production and consumption of the global economy, and hence much of the emissions of greenhouse gases [6,7]. At present, cities contribute more than 75% of the global pollution and use more than 70% of the energy consumed by humankind. Resources of many kinds are involved in the construction and operation of human settlements, building materials, energy, water, waste among others [8].

Energy is a paramount issue when considering the design of human settlements [8]. In statistics, energy consumption is commonly divided into three main categories, namely, Industry, Buildings and Transport. The category of buildings excludes industrial buildings, and it consists of two subdivisions: residential and tertiary or, the household and service sector, and it comprises the largest end use of energy [9]. The use of energy in buildings is often physically invisible to consumers, the status and comfort of using energy will only be visible to the energy buyers themselves and to others [10]. As a side-effect, buildings contribute half of the CO_2 emissions sent into the atmosphere. Energy use in the construction sector consumes non-renewable resources and sends out the greenhouse gases that are the main cause for Climate Change. Most industrialized countries are, in addition, becoming more and more dependent on external supplies of conventional energy carriers, e.g. fossil fuels [11]. Together with environmental pressure, the import dependence on fossil resources calls for urgent measures to reduce the energy demand. In many countries, global warming considerations have led to efforts to reduce fossil energy use and to promote renewable energies in the building sector that can be achieved by minimizing the energy demand, by rational energy use, by recovering heat and cold, by using energy from the ambient air and from the ground [11]. Consumption tends to increase, especially that of electricity. In the EU, the residential and tertiary sector buildings consume roughly 40% of the total final energy use [9]. The new EU Action Plan on energy-efficiency presents a goal to limit the increase of the global average temperature to 2 °C, compared to pre-industrial levels. To achieve this, the EU is promoting a goal of 30% reduction in greenhouse gas emission in developed countries by 2020 compared to 1990 levels [12].

In sectors such as the residential and the commercial ones, the major part of energy consumption takes place in buildings, which constitutes almost 40% of the total final energy used in the world [10]. The value includes energy used to control the temperature in buildings, appliances, lighting and other installed equipment, and the buildings themselves: embodied energy, that is the energy consumed by all processes associated with the production of a building. Still more, research has shown that low-energy buildings result in being more energy efficient than conventional ones, even though their embodied energy is somewhat higher [13]. Buildings and construction products have a significant socio-economic relevance and the sector has high initial and follow-up expenditures, long life-cycles and require a large amount of materials and energy [14]. In the Mediterranean region, the problem of energy consumption is more complex (the air-conditioning load is as important as the heating load) [15]. In Mexico the residential sector consume around 83.6% of the total [16].

The residential sector is a substantial consumer of energy in every country, and therefore a focus of energy consumption efforts [17]. Nation-wide, energy consumption in the residential sector accounts for 16% (Finland) to 50% (Saudi Arabia) of that consumed by all sectors (world average = 31%). This significant consumption level guarantees a detailed understanding of the residential sector's energy consumption in an increasingly energy-aware world. In response to climate change, high energy prices, and new energy supply/demand patterns, there is interest in understanding the detailed consumption characteristics of the residential sector in an effort to promote conservation, efficiency, technology implementation and energy source switching, such as on-site renewable energy [18,19]. The energy consumption characteristics of the residential sector are complex and inter-related [17]. Household energy consumption depends on the location, design and construction of a dwelling, and on the specifications of the heating systems and their controls [20], together with the efficiency of appliances [21] and the behaviour and socio-demographical characteristics of occupants [22–24].

In the last decade, several transitional and developing countries have undergone fast growth, which does not correlate with improvements in building techniques and codes that usually require research efforts and policy discussions within a longer time frame [25]. The building sector in Argentina accounts for one of the largest industrial activities in the country. In the last years, the statistical records show an increase in the number of dwellings built in Argentina (Fig. 1). In the period 2003–2008, the residential building sector has had an average annual growth of 11% [26]. In many cities in Argentina we can see a sharp increase in the density of specific

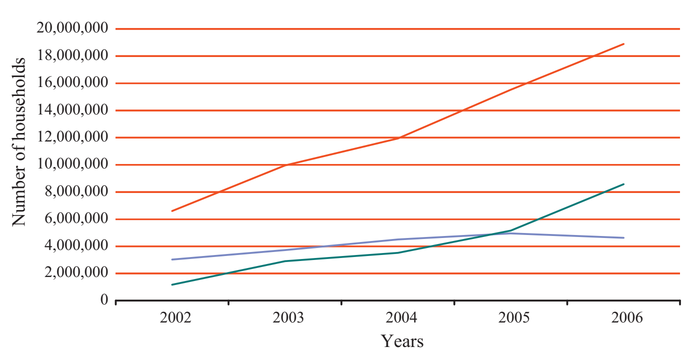

Fig. 1. Evolution of number of household in Argentina.*Source*: INDEC (2006).

areas originated in the construction of housing which are rapidly changing the face of such cities. The consequences from the point of view of energy, water supply, effluent disposal, urban heating, etc. have not been taken into account [27]. Residential energy consumption increased 2.5% in the period 1996–2005. According to energy consumption patterns, the CO_2 emission growth rate was 2.18% for the same period [28]. Residential energy consumption shows a percentage of around 53% of national energy consumption, out of which 58% is used to heat residential buildings [29]. Several studies have shown that energy consumption in residential buildings in Argentina is very high compared to buildings in similar European climate zones. For example, in the cold region of Patagonia, a study showed that a one-family house in the city of Bariloche (mean temperature 8 °C) uses really four times more heating energy than the same type in Stockholm (Sweden, mean temperature 7 °C). Gonzalez [30] reported that there are two main reasons for this high-energy consumption: low building thermal quality and poor furnace efficiency. Regarding furnace efficiency, Juanicó and González [31] developed a prototype with simple and low-cost modifications introduced to commercial models, and measured the improvements against thermal efficiency. Gonzalez [26] reported that in Argentina energy is generally perceived as money to pay, and low energy bills discourage investments in technological improvements. Furthermore, the subsidies are not income-sensitive and not equally distributed, i.e. all households enjoying natural gas pay the same unit price of heavily subsidized energy (around 40% of households are not connected to natural gas and pay per unit of energy a price 5–20 times higher than that of natural gas). This is probably the single, most convincing reason for middle-high and high income households not to choose better thermal performance buildings, even though they can afford them. In Argentina, nation-wide fuel prices are low in relation to international ones, with natural gas being the cheapest per energy unit. Natural gas price for the residential and part of the business sector is US$ 2/MBTU, which is between 5 and 15 times lower than international prices [31]. Obviously a transition away from fossil fuel dependency is needed [32].

2. Purpose of the work

In this context, and due to the fact that people spend more than 80% of their lives inside buildings, building professionals, building and environmental scientists and policy makers should tend to achieve comfortable, healthy, productive indoor environmental and low energy consumption buildings. The general objective of this study is: (a) to evaluate the thermal and energy behaviour of multifamily dwellings in Santa Rosa (capital city of the province of La Pampa) located in the central region of Argentina, and the indoor thermal environmental comfort, (b) to study proposals for thermal improvement.

The specific objectives are:

a. To evaluate the thermal behaviour during the 2009 winter through monitoring.
b. To analyze energy consumption, thermal comfort and owner's opinions.
c. To analyze energy consumption for heating in years before 2009 and to contrast findings with the thermal performance during monitoring.
d. To explore potential energy and feasible interventions to reduce energy consumption.

2.1. Location of buildings

Much of the territory of the province of La Pampa is part of the vast Pampas plains; however, there are some variations in its relief. The Pampas is a transition area located towards the East of the Cuyo region and North of Patagonia, with a height above sea level between 600 and 1100 m. The climate is temperate, rainfall exceeds 500 mm per year in the NE and decreases towards the West (Fig. 2).

The city of Santa Rosa (capital of the province of La Pampa) is located in a cold temperate climate. The mean and absolute minimum temperatures during July are -11.2 and 7.6 °C, respectively. The annual heating degree-days (temperature base = 18 °C) is 1545 (see Table 1). Santa Rosa has more than 100,000 inhabitants and has shown a very high growth in construction in recent years, especially towers of multifamily housing with large glazed areas without sunscreens. Between 2005 and 2007 new construction developments increased around 24% (85% are apartment towers). Building remodelling and enlargement grew about 42.8% [33]. As stated above, this rate is similar to what happens in other urban centres in the country. From the energy point of view, an increased power consumption in the city (electricity and natural gas) has been recorded in the residential sector. According to the Electricity Company, the electricity consumed was mainly used in the domestic sector. The consumption-per-user rate increased 5.6% between 2008 and 2009. The average annual consumption was around 2380 kWh per-user [34]. According to the Gas Distribution Company, around 67% of the natural gas consumed annually (average annual natural gas consumption per-user = 1420 m^3) is used for heating buildings and, during winter, around 75% of the total gas consumed is used to heat buildings.

Climatic design is one of the best approaches to reduce the energy cost in buildings. Proper design is the first step of defence against the stress of the climate. Buildings should be designed according to the climate of the site, reducing the need for mechanical heating or cooling. Hence, maximum natural energy can be used for creating a pleasant environment inside the built envelope [11]. Since the city records high consumption of heating resources, it seems relevant to visualize through diagrams the

Fig. 2. Province of La Pampa in Argentina. Landscape – City.

Table 1
Climatic data of Santa Rosa, La Pampa, Argentina (36°57′S, 64°27′W, 189 m.a.s.l.).

Annual values	Maximum	Mean temperature	23.4 °C
	Minimum		8.1 °C
	Mean		15.5 °C
	Global horizontal irradiance		16.3 MJ/m^2
	Relative humidity		68%
July	Minimum	Mean temperature	1.5 °C
	Mean		7.6 °C
	Maximum		13.5 °C
	Thermal amplitude		12.0 °C
	Mean wind velocity		2.8 m/s
	Global horizontal irradiance		8.1 MJ/m^2
	Mean ground temperature (−1.00 m)		10.0 °C
January	Maximum	Mean temperature	31.9 °C
	Mean		23.8 °C
	Minimum		15 °C
	Thermal amplitude		16.9 °C
	Mean wind velocity		3.9 m/s
	Global horizontal irradiance		24.0 MJ/m^2
	Mean ground temperature (−1.00 m)		23.8 °C
Annual heating degree days (Tb = 16 °C)			1136
Annual heating degree days (Tb = 18 °C)			1545
July–August heating degree days (Tb = 16 °C)			939
Annual cooling degree days (Tb = 23 °C)			128

Servicio Meteorológico Nacional – Fuerza Aérea Argentina (National Forecasting Service-Argentine Air Force) (period = 1990–1999).

requirements in terms of natural air conditioning to meet the inhabitants' levels of comfort. Simplified PC softwares are available, that allow us to know which are the most appropriate building's bioclimatic design strategies on the basis of monthly mean temperature and relative humidity data [35]. Thus, it is possible to roughly estimate hourly heating and cooling needs. Fig. 3 shows that 59 and 21.9% of the time heating and cooling are needed to meet comfort conditions respectively. 19.1% of the remaining time there would be a situation of comfort. The temperature of comfort in the software is determined according to the mean temperature for the month of the study area and as indicated by the expression $T_n = 17.8 + 0.31 \times T_m$. The comfort zone can be taken as $T_n - 2.5\,°C$ to $T_n + 2.5\,°C$ [36].

According to temperature and relative humidity values, Fig. 4 shows that from May to August, passive heating and auxiliary heat are needed to reach the comfort area. For the minimum mean temperature values along the four months, solar availability above 5000 Wh over the vertical surface facing north is needed (Fig. 4). According to Table 2, the resource availability could not meet the demand, thus, auxiliary heat was needed (conventional energy). The available solar energy would not be enough to meet mean and maximum mean temperatures. This description allows us to confirm the behaviour of the energy consumed in the region under study. Fig. 5 shows the psychrometric chart for summer. It can be observed that only the mean values (temperature and relative humidity) corresponding to December, January and February fall into the comfort area. Both November and March would need some solar heating to reach the comfort area. Considering the maximum mean temperature values of December, January and February, it is evident that the latter would need mechanical cooling. In November and March, thermal inertia, natural ventilation and night ventilation would be sufficient. In the case of minimum mean temperature values (maximum humidity), solar energy as resource would be needed to heat indoor air and reach the comfort area in all months. During November and March, values of about 3500 W/m^2 over the vertical surface facing north would be needed.

3. Case study

Fig. 6 shows a photo of the Block Buildings built during the 60s. Fig. 7 shows the building plant design and its cross section. Access to the building is located on the façade having a 120° azimuth (South = 0°).

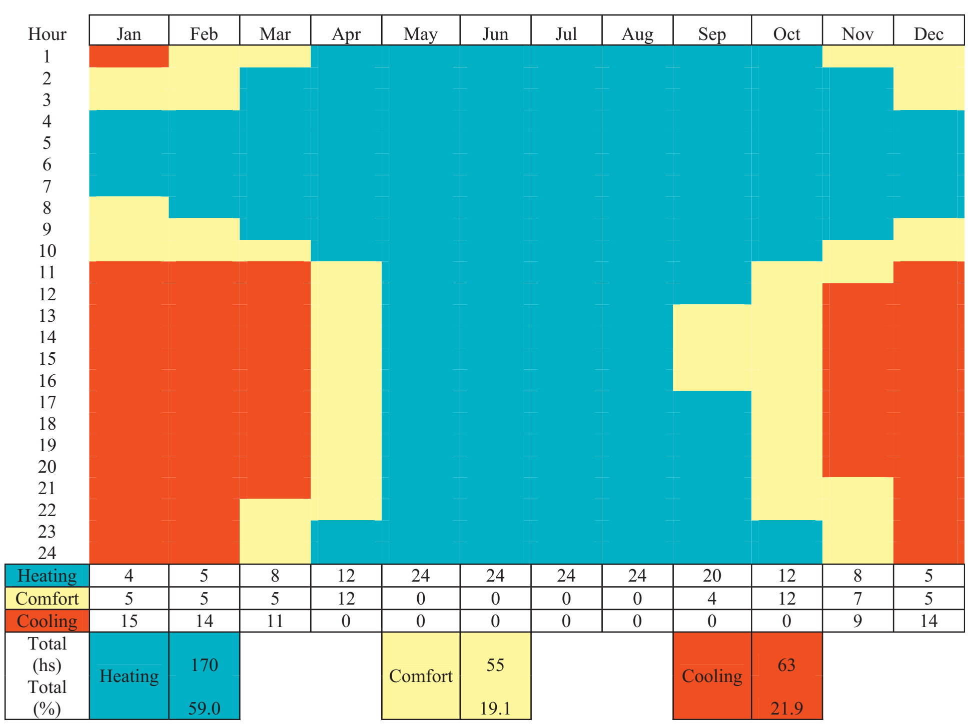

Fig. 3. Hours of heating and cooling requirements.

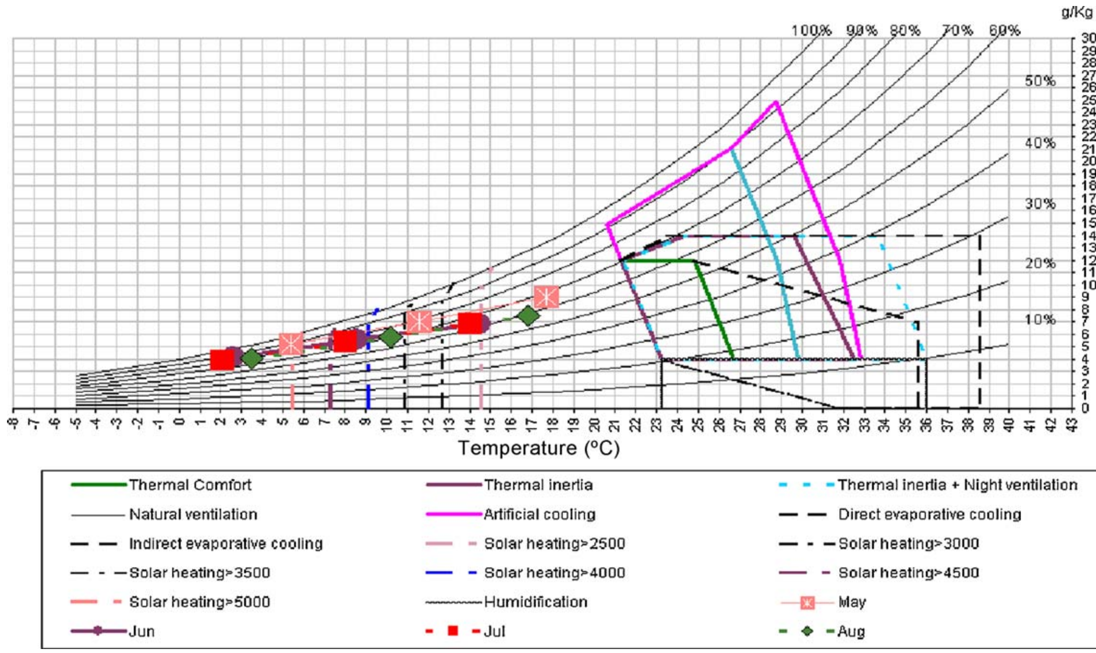

Fig. 4. Winter psychrometric chart.

The buildings have an independent structure of reinforced concrete and hollow ceramic brick walls. The walls and roof do not have thermal insulation. IRAM Norm 11605 [37] recommends for the study region maximum values of thermal transmittance (K). In winter (outdoor design temperature = −3 °C); the same Norm recommends 0.33, 0.91 and 1.59 W/m^2 °C (Levels A, B and C) for walls, while for roofs: 0.29, 0.74 and 1.00 W/m^2 °C (Levels A, B and C). Under summer conditions it recommends walls of 0.5; 1.25 and 2 W/m^2 °C for level, B and C, respectively. Likewise, the same Norm establishes for roofs: 0.19, 0.48 and 0.76 W/m^2 °C.

Table 3 shows some dimensional and energy indicators The FAEP value (relationship between envelope area and covered area) [38] increases toward the upper floor. The wall shows a K value = 1.84 W/m^2 °C, and the roof has a K value = 3.82 W/m^2 °C. None of the preceding values meets Iram Norm 11605 level C. Under summer conditions the K value on walls meets the Norm level C, whereas the roofs' thermal transmittance ranges far from the Norm standard. Thus, the Global Loss Coefficient 'G' partly defined by the roof's thermal resistance varies between 2.46 and 2.76 W/m^3 °C and shows higher values than those considered acceptable (IRAM Norm 11604 [39]). To the Global Loss Coefficient we should add the Q_{aux} (auxiliary heat) value that tends to increase toward the upper floor, fact that is foreseeable due to the fact that the envelope offers low thermal resistance having higher outdoor contact. The functional areas (dining-room, bedroom, kitchen and bathroom) of the apartments have the minimum dimensions required by the building code.

Table 2
Solar resource availability on a vertical surface facing North.

Months	Daily solar irradiance over horizontal surface (MJ/m^2)	Daily solar irradiance on a vertical surface facing North[a]	
		MJ/m^2	Wh/m^2
May	8.9	10.59	2944
June	7.8	12.65	3517
July	8.1	11.41	3172
August	11.2	12.91	3589

[a] The record was estimated through the Geosol Software with Liu Jordan's method [45].

4. Background

A previous work allowed us to evaluate annual and seasonal natural gas consumption in the 192 apartments distributed in 8 blocks for the period 2001–2006. Having this analysis as a point of departure, no variation of the total annual consumption among the 8 blocks was found. Results showed that in the case of equal useful surface area but less FAEP, the first level in each block consumes less natural gas. Variation in the consumption of heating gas according to orientation and spatial location was observed; for example, the apartments located on the ground floor (Block 326), on both ends, having greater outdoor contact (FAEP = 0.63) consumed 25% more gas than those on the first floor (FAEP = 0.48). The influence of orientation and of the apartment's location in the block and/or the use of a particular design strategy were previously studied. Apartments receiving solar gains from the north consumed 36% less heating energy than those facing south [40,41].

As one of the objectives of this study is the thermal monitoring of the building during the 2009 winter to assess the conditions of comfort and energy consumption, and on the basis of previous results, we could establish certain conditions that serve as units of analysis for the present work:

(a) Good state of conservation and maintenance of block and apartments.
(b) Low variability in their energy consumption historical records, guaranteed by the permanence of the same dweller during a given historical period.
(c) Very good predisposition of dweller to place monitoring sensors and to answer a questionnaire.

Following previous arguments, it could be observed in a previous work that 50% of all the apartments in Block 126 showed little variability in energy consumption between 2001 and 2006 (Fig. 8). During 2009, after interviewing dwellers, they accepted the fact that their apartments be monitored and offered cooperation to answer a questionnaire. Three apartments under study – 15, 18 and 23 – have different orientation and are located on the first and second floors (Fig. 9). Table 4 shows some dimensional indicators.

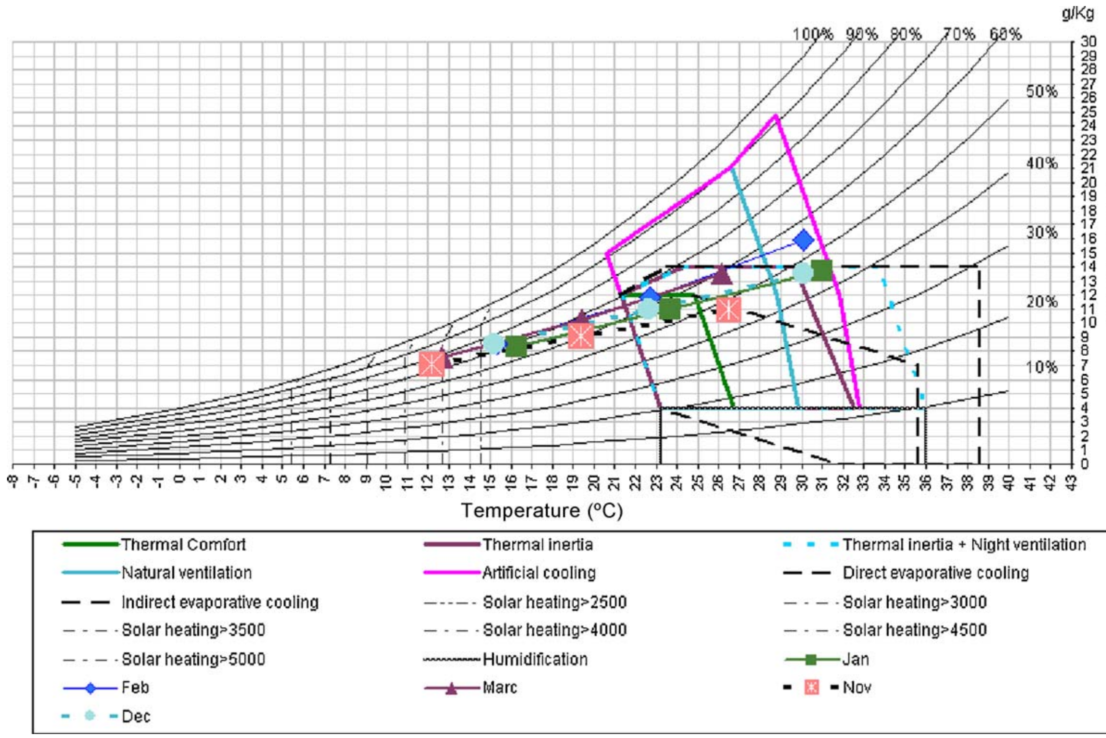

Fig. 5. Summer psychrometric chart.

Fig. 6. Pictures of the buildings.

An apartment from Block 374 (Apartment 12, second floor) is added to the study, which presents a characteristic that is repeated in various blocks: its balcony has been closed with single glass carpentry. Table 5 shows the natural gas consumption during the new study period (2001–2009). According to the previous analysis (2001–2006), the annual average natural gas consumption in Apartments 15, 18 and 23 was 956.7, 708.8 and 1150.8 m^3, respectively (33,533, 24,843.7 and 40,336 MJ). The coefficient of variability over the period (15.9, 10.7 and 8.8%) was slightly lower than for the period 2001–2009. The winter of 2007 was the coldest

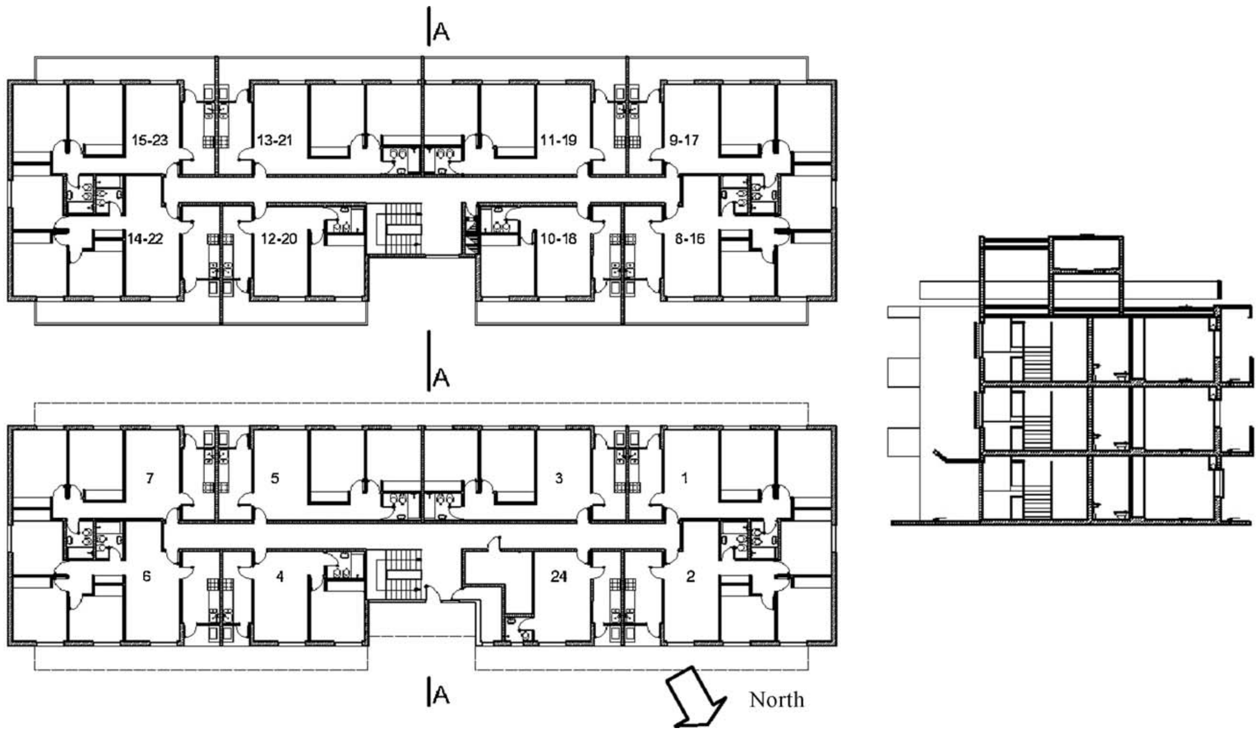

Fig. 7. Plant view and section.

Table 3
Dimensional, morphological and energy indicators. References: FAEP = envelope area factor/floor[a], G = volumetric heat loss coefficient[b].

Level	Apartments	Area (m^2)	Envelope (m^2)	Volume (m^3)	FAEP	G-value (W/m^3 K)
Ground floor	1–6	65.8	41.6	171.1	0.63	2.46
	2–7	50.2	35.4	130.5	0.70	2.42
	3–4	50.8	24.2	132.0	0.48	2.31
	5–24	36.5	18.2	95.0	0.50	2.15
First floor	8–14	65.8	41.6	171.1	0.63	2.54
	9–15	50.2	35.4	130.5	0.70	2.55
	11–13	50.8	24.2	132.0	0.48	2.52
	10–12	36.5	18.2	95.0	0.50	2.4
Second floor	16–22	65.8	107.4	171.1	1.63	2.9
	17–23	50.2	85.6	130.5	1.70	2.89
	19–21	50.8	75.0	132.0	1.48	2.87
	18–20	36.5	54.7	95.0	1.50	2.76

[a] Esteves et al. [38].
[b] The total heat loss of a dwelling through the fabric and ventilation, divided by the heated volume.

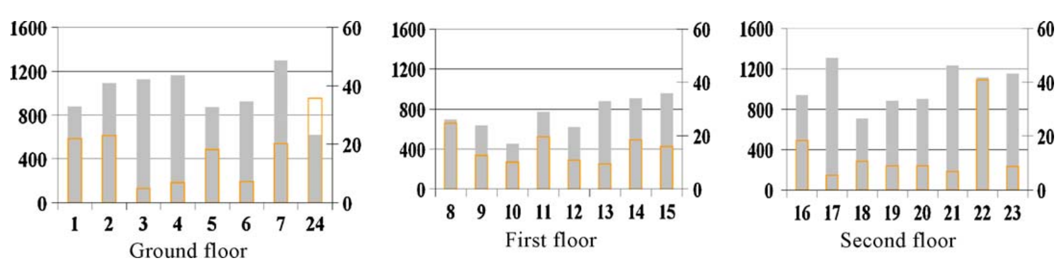

Fig. 8. Natural gas average consumption and its variability between 2001 and 2006 in Block 126. References: axis y = annual natural gas consumption (m^3); secondary axis y = variability (%); axis x = apartments.

Fig. 9. North (1–2–3) and South (4) facades of the block 126.

Table 4
Dimensional, morphological and energy indicators.

Level	Apartment	Azimuth	Area (m^2)	Envelope (m^2)	Volume (m^3)	FAEP	G-value ($W/m^3\,°C$)
First floor	12	120	45.3	18.2	95.0	0.50	2.40
	15	200	52.0	35.4	130.5	0.70	2.55
Second floor	18	120	38.3	54.7	95.0	1.50	2.76
	23	200	52.0	85.6	130.5	1.70	2.89

Table 5
Average natural gas consumption in MJ during the period 2001–2009 in Block 126. References: SD: standard deviation; VC: variability coefficient. 1 m^3 natural gas = 8400 kcal[a].

Bi-month	Apartments											
	15			18					23	12		
	Average (MJ)	SD (MJ)	VC (%)	Average (MJ)	SD (MJ)	VC (%)	Average (MJ)	SD (MJ)	VC (%)	Average (MJ)	SD (MJ)	VC (%)
Period 2001–2009												
1	1791.5	266.0	14.9	1390.3	180.4	13.0	2644.4	812.6	30.7	245.4	297.9	121.4
2	2282.2	662.4	29.0	1542.2	538.5	34.9	3185.7	856.1	26.9	420.6	273.4	65.0
3	7325.5	1739.1	23.7	5354.9	577.5	10.8	8875.5	1039.3	11.7	788.6	273.4	34.7
4	10807.2	1844.7	17.1	8653.5	2853.7	33.0	13338.6	1835.8	13.8	858.7	420.6	49.0
5	6963.3	1383.4	19.9	5970.2	895.3	15.0	9323.4	1541.6	16.5	683.5	171.7	25.1
6	2597.6	628.8	24.2	2068.0	387.9	18.8	3762.1	375.5	10.0	613.4	420.6	68.6
Total annual			31767.3			24979.2			41129.6			3487.5
Average (MJ)			5296.1			4163.9			6858.8			602.9
SD (MJ)			3631.2			2958.2			4311.2			231.3
VC (%) over the year			68.6			71.1			62.9			38.4
Period average (MJ)			31767.3			24979.2			41129.6			3487.5
Variability over the period	SD (MJ)		5285.6			3757.4			4549.5			420.6
	VC (%)		16.6			15.0			11.1			12.0

[a] Eduardo Jahnke S. (2009). Evaluación económica de alternativas de calefacción. www.territorioverde.cl.

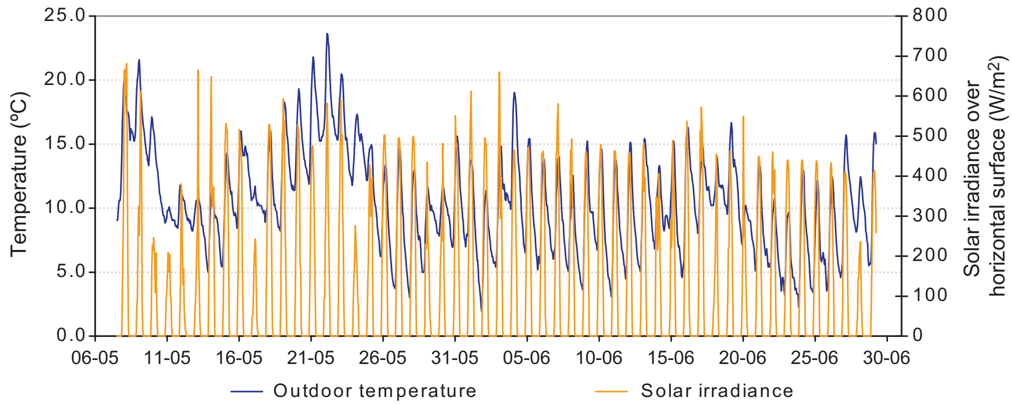

Fig. 10. Evolution of outdoor temperature and solar irradiance between May and June, 2009.

Table 6
Mean and absolute temperature and solar irradiance during the study period.

Month	Temperature (°C)			Solar irradiance over horizontal surface (W/m^2)
	Mean	Absolute		
		Maximum	Minimum	
May	12.2	23.6	3.0	Predominance of days with clear sky Maximum irradiance 681 W/$^{2\cdot}$ During the days 10 and 11, the maximum value of solar irradiance was 200 W/m^2. During the days 17 and 24 the maximum values were 250 W/m^2. There is also a drop in temperature.
June	9.3	16.7	2.2	Maximum irradiance = 660 W/m^2 except June 27 = 200 W/m^2.

with an absolute minimum temperature in June close to −10 °C. This year showed an increase in natural gas consumption.

5. Thermal monitoring under real conditions of use between May 1 and June 29, 2009

For the monitoring phase, Data Loggers HOBO H8 Series sensors located in every functional area were used. Solar irradiance on horizontal surface data was provided by the College of Agronomy, located 10 km away from the city of Santa Rosa. The outdoor temperature was also recorded in an urban area with Data Logger HOBO Pro Series Weatherproof. Fig. 10 shows outdoor temperature and solar irradiance over the horizontal area. Table 6 shows monthly average and absolute outdoor temperature in the period between May 5 and June 29, 2009. The absolute mean, maximum and minimum in May were 0.8, 5.9 and 1.7 °C above the average values for the period 1977–2001. During June, the absolute minimum was 1 °C above the historical averages.

6. Results

6.1. Apartment 12 (Block 374)

This functional unit is located on the first floor. Part of the exposed exterior wall of the only bedroom also faces the block entrance door (oriented NW). The balcony was closed with aluminium carpentry and single glass. It shows four sliding-door panels. Fig. 11 shows the north front of the apartment. The photos below, taken on June 30 2009 show the closed balcony and a view from the bedroom onto the glazed balcony with its open window. The apartment does not have a gas heater. The dweller uses a 1200 W oscillating halogen heater (three levels = 400–800–1200) that is turned on during 1 h in the morning and between 9 pm and 2 am approximately in the evenings/nights).

Fig. 12 shows the apartments thermal behaviour during May and June 2009. Between May 10 and 13, the indoor drop in temperature (very marked in the closed balcony) is observed, at a time when temperature decreases outdoors and the maximum

Fig. 11. North view. Apartment 12 (first floor) Block 374. View of the glazed balcony and from bedroom to balcony.

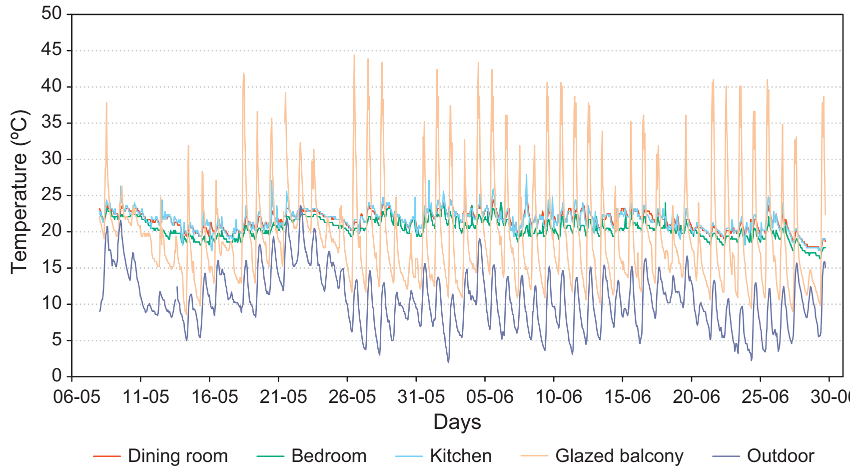

Fig. 12. Evolution of temperature in Apartment 12 during May and June 2009.

Table 7
Indoor average temperature (°C) in Apartment 12 during the monitoring period.

Period	Statistical indicators	Average temperature in different functional areas				Average temperature (°C)		
		Balcony buffer space	External bedroom	Dining-room	Kitchen	Apartment		Outdoors
						With balcony buffer space	Without balcony buffer space	
May	Average (°C)	21.3	21.5	22.3	22.6	21.9	22.1	12.2
	SD (°C)	6.7	1.9	1.7	2.0			4.0
	VC (%)	31.3	8.8	7.5	8.7			33.2
June	Average (°C)	19.2	20.2	21.4	21.5	20.6	21.0	9.3
	SD (°C)	7.7	1.4	1.4	1.6			3.3
	VC (%)	39.8	6.8	6.7	7.3			35.2

radiation was of the order of 200 and 320 W/m^2. A similar situation can be observed toward the end of May (mean temperature of the month 1 °C above the period's mean for 1977–2001). The apartment's mean temperature, without mechanical conditioning system, was 21.9 °C (including the balcony), 9.7 °C above the outdoor mean temperature (12.2 °C). During the month of June the indoor mean temperature was 20.6 °C (8.4 °C above the mean outdoor temperature) (Table 7). Toward the end of June a drop in temperature was observed (day 28 irradiance = 210 W/m^2). The experimental results show the adequate use of the closed balcony as a climatization passive solar system (the owner does not use the balcony as a place to be). An improvement in the convection heat transfer by increasing the air velocity would optimize the use of this space as solar heating system and an adequate shading would prevent overheating in warm periods. The results of the monitoring in summer 2008 shows overheating in the apartment (unpublished data).

From the complete monitoring period only the last days of the month of June are analyzed. In Fig. 13 it can be observed a rise in temperature in the dining-room/sitting room between 8 pm and 2 am in agreement with the use of the halogen heater. A similar situation is observed up to day 27, day after which the apartment remained uninhabited. Even with little solar irradiance (day 28 was cloudy) the indoor temperature did not drop below 18 °C.

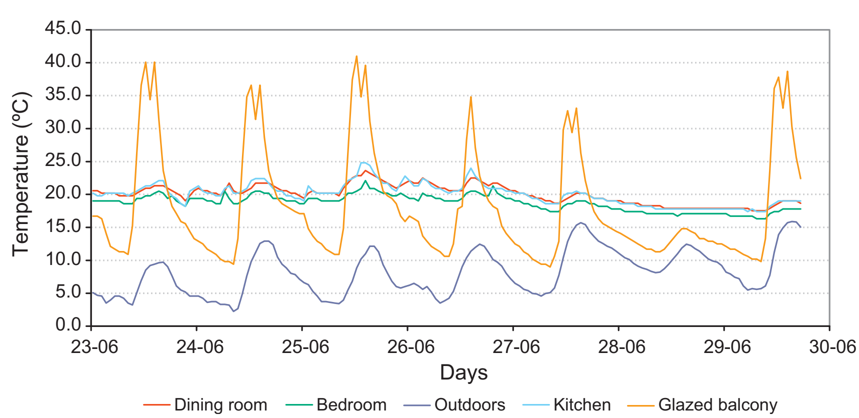

Fig. 13. Evolution of temperature and solar irradiance in Apartment 12 between June 23 and 29 2009.

Fig. 14. Southeast facing. Apartment 15 (first floor) and Apartment 23 (second floor).

6.2. Apartment 15 (Block 126)

The apartment is located on the first floor, on the SE end. It has two bedrooms, one of them with two walls facing outdoors (Fig. 14). The owner, a retired teacher, lives there since the end of the 60s when the blocks were inaugurated. She introduced only one change: extending the kitchen and thus occupying part of the balcony. The apartment has a gas heater (6000 kcal) in the dining-room. The annual average natural gas consumption between 2001 and 2009 was 906.3 m^3 (31,767.3 MJ) (variability coefficient along the period = 16.6%). The bimonthly average consumption was 151.1 m^3 (52,961.1 MJ), with a variability along the year of 68.6% (showing gas consumption seasonality). The highest consumption rate corresponds to period 4 (July–August) with an average value for the period of 308.3 m^3 (10,807.2 MJ) (VC = 17.1%). In a second step, period 3 (May–June) shows an average around 209 m^3 (7325.5 MJ) (VC = 23.7%). The winter heating percentage is, according to estimates from the Gas Company, of around 75%. The historical annual average electricity consumption between 1996 and 2006 was 1833.9 kWh (VC = 13.2%). The monthly average consumption was 154.0 kWh with a 10% variability along the year.

In Fig. 15 it can clearly be observed the moment the heater placed in the dining-room was turned on (May 11). There were two periods during which the apartment was closed and the heater switched off: May 7–10 and June 7–11. Between May 18 and 22, outdoor temperature rose (between 20 and 24 °C) and the heater was switched off (indoor temperature was of about 24 °C). The rest of the days, the heater was turned on and the mean temperature during the monitoring period ranged between 24.9 and 25.7 °C, with a variability of about 10% and 10.6%, showing the room's thermal amplitude (red line in the Figure). During May, the maximum temperature in the dining-room, with minimum dimensions (3.00 × 4.90 m), reached 30 °C. On May 16 and May 17 it climbed to around 32 °C (outdoor temperature = 14 and 15 °C). The minimum temperature did not fall below 21 °C. During June, days with maximum temperatures above 30 °C (outdoor temperatures do not exceed 15 °C) prevailed. According to owner's habits (retired teacher) the dining-room is used most of the day as a workplace, computer room and reading area. Surely, sedentary life, low external temperatures and low solar resource availability determine the thermal behavior of the area. The apartment's average temperature in May and June was 22.5 and 22.0 °C (10.3 and 9.8 °C above the outdoor mean) (Table 8). It is therefore important to note that the heater is turned off in the absence of the owner.

The monthly natural gas consumption during May and June (monitoring period) was 121 m^3 (4254.6 MJ). According to the Gas Distribution Company, heating energy consumption was 90.75 m^3 (121 × 0.75) (3191 MJ). For 40 days of use, the daily heating energy consumption was around 2.3 m^3 which correspond to 0.43 kWh/m^2/day.

6.3. Apartment 23 (Block 126)

This apartment is located on the second floor, on the SE end and on top of Apartment 15 (Fig. 14). It has two bedrooms, one of them with two walls facing outdoors. As in the previous cases, all functional areas have minimum dimensions (bedroom has 3.00 × 3.30 m). The owner, an elderly woman, lives there since the end of the 60s when the blocks were inaugurated. Only one change is observed: the kitchen occupying part of the balcony. The apartment has two gas heaters, one in the dining room and the other in the internal bedroom. The annual average natural gas consumption between 2001 and 2009 was 1173.4 m^3 (41129.6 MJ), with a variability along the period of around 11.1% (VC). The bimonthly average consumption was 195.6 m^3 (6858.8 MJ), with a variability (VC) along the year of 62.9% (showing gas consumption seasonality). The highest consumption rate corresponds to period 4 (July–August) with an average value for the period of 366.0 m^3 (13,338.6 MJ) (CV = 10.3%). The monthly average electricity consumption was 382.9 kWh, with a variability along the year of 13.5%. There is a 148% increase with respect to Apartment 15, located below 23 in the same block. This difference

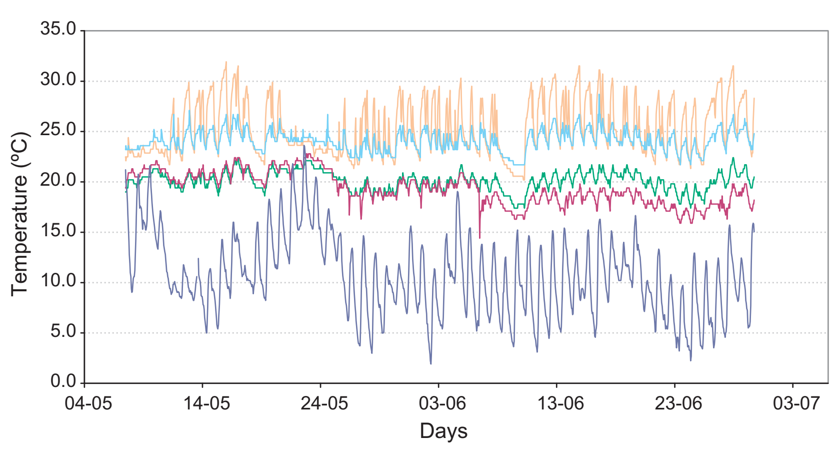

Fig. 15. Evolution of indoor temperature in Apartment 15 during May and June 2009.

Table 8
Indoor average temperature (°C) in Apartment 15 during the monitoring period.

Period	Statistical indicators	Average temperature in different functional areas				Average temperature (°C)	
		External bedroom	Intermediate bedroom	Dining room	Kitchen	Apartment	Outdoors
May	Average (°C)	20.5	20.8	24.9	24.1	22.5	12.2
	SD (°C)	1.0	1.3	2.5	0.9		4.0
	VC (%)	5.0	6.1	10.0	3.7		33.2
June	Average (°C)	19.9	18.3	25.7	24.1	22.0	9.3
	SD (°C)	1.0	1.1	2.7	1.1		3.3
	VC (%)	4.9	5.9	10.6	4.7		35.2

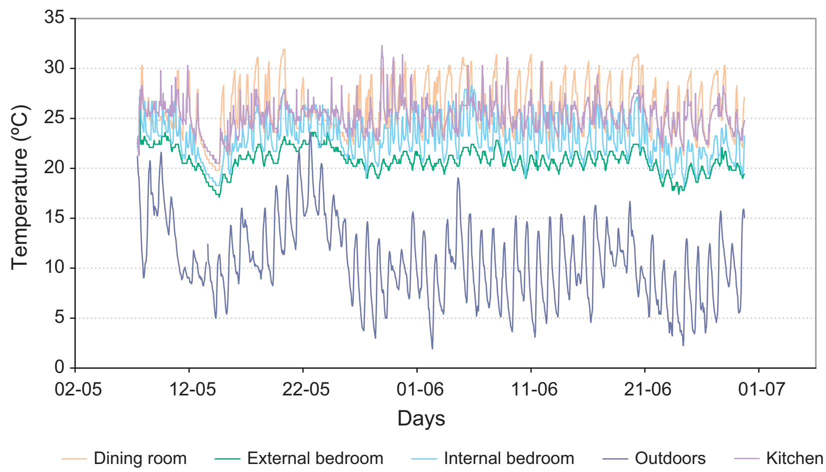

Fig. 16. Evolution of indoor temperature in Apartment 23 during May and June 2009.

is reasonable since Apartment 23 shows a high degree of outdoor exposition through walls and roof with high heat loads during summer. The apartment has two air conditioner.

Fig. 16 shows temperature evolution during May and June. As expected, the line corresponding to the external bedroom which has a bigger vertical envelope surface area in contact with the exterior, is placed underneath with an average temperature of 21.1 and 20.5 °C for May and June, respectively. The dining room, as well as the kitchen showed an average temperature of 25.4 and 26.2 °C for both months. The intermediate bedroom is located between both functional areas and shows an average temperature of about 23.0 and 22.8 °C. For the whole period, the apartment shows and average temperature of 23.7 °C (outdoor average temperature = 10.8 °C) (Table 9).

The natural gas consumption and heating energy during May and June 2009 was 233 and 174.7 m^3, respectively (8193 and 6145 MJ). Daily heating energy consumption was 2.9 m^3 (100.7 MJ). The apartment needs about 0.54 kWh/m^2 to keep an average temperature of 23.7 °C. This apartment shows energy loss through the roof which does not have thermal insulation but receives heat transfer from the floor below. For this reason, probably, the owner does not turn on the heater during the day and turns on at night.

6.4. Apartment 18 (Block 126)

This apartment is located in the centre of the second floor, next to the entrance door, facing North. It has one bedroom with two walls facing outdoors. The apartment has one gas heater in the dining-room. The annual average natural gas consumption between 2001 and 2009 was 712.7 m^3 (24979.2 MJ) with a variability along the period of around 15.0%. The bimonthly average consumption was 118.8 m^3 (4163.9 MJ), with a variability along the year of 71.1% (showing again the seasonality of gas consumption). The highest consumption rate corresponds to period 4 (July–August) with an average value for the period of 246.8 m^3 (8653.5 MJ) and a variability along the period 2001–2009 of around 33%, the highest value between apartments (during 2009

Table 9
Indoor average temperature (°C) in Apartment 23 during the monitoring period.

Period	Statistical indicators	Average temperature in different functional areas				Average temperature (°C)	
		External bedroom	Intermediate bedroom	Dining room	Kitchen	Apartment	Outdoors
May	Average (°C)	21.1	23.0	25.4	21.1	23.7	12.2
	SD (°C)	1.4	2.0	2.5	1.4		4.0
	VC (%)	6.7	8.5	9.7	6.7		33.2
June	Average (°C)	20.5	22.8	26.2	25.2	23.7	9.3
	SD (°C)	1.0	2.0	2.5	1.4		3.3
	VC (%)	5.0	8.9	9.6	5.7		35.2

Table 10
Indoor average temperature (°C) in Apartment 18 during the monitoring period.

Period	Statistical indicators		Average temperature in different functional areas			Average temperature in the apartment (°C)	Outdoor temperature (°C)
			External bedroom	Dining room	Kitchen		
May		Average (°C)	21.4	22.2	23.8	22.5	12.2
		SD (°C)	1.0	0.9	1.0		4.0
		VC (%)	4.8	4.2	4.6		33.2
June	1	Average (°C)	20.8	22.0	23.3	22.0	9.3
		SD (°C)	0.8	0.8	0.8		3.5
		VC (%)	3.6	3.6	3.5		36.9
	2	Average (°C)	15.9	17.1	17.9	17.0	9.3
		SD (°C)	1.2	1.1	1.2		3.3
		VC (%)	7.5	6.2	6.5		35.2

References: 1, under real conditions of use; 2, unoccupied.

the consumption dropped down to 55 m^3 (1927.8 MJ). The historical annual average electricity consumption between 1996 and 2006 was 687.0 kWh (CV = 9.9%). The monthly average consumption was 57.7 kWh, with a variability along the year of 7.2%.

Table 10 shows the average temperature during the monitoring period. In June, and until day 12, measurements were carried out under real conditions of use, with sporadic switching of the heater. Since June 13 at 0 am the apartment was unoccupied (Fig. 17). The mean temperature in the bedroom was 2.5 °C lower than that in the kitchen. The apartment's mean temperature was 22.0 °C, 12.6 °C above the outdoor mean (9.4 °C). During the time in which the apartment was not occupied and without the use of heater, the mean temperature was 17 °C, 7.6 °C above the outdoor mean (9.4 °C). In Table 10, heat transfer from the kitchen to the room with higher degree of outdoor exposition is clearly observable. The difference in mean temperature between the apartment measured under real conditions of use or unoccupied was of 5 °C (in both periods the outdoor mean temperature was 9.4 °C). These 5 °C correspond to indoor gains and auxiliary heat input.

The natural gas consumption and energy heating during May and June 2009 were 110 and 82.5 m^3, respectively (3867.9 and 2900.9 MJ). Daily heating energy consumption during 43 days was 1.9 m^3 (67.5 MJ). The apartment needs about 0.48 kWh/m^2 to keep an average temperature of 22.2 °C (Table 11).

7. Energy behaviour and comfort

Fig. 18 shows temperature and relative humidity daily values, indoors and outdoors, on a dot plot. The cloud of blue dots corresponds to outdoors, the orange one to indoors. In Apartment 12 (Block 374) and for the complete indoor monitoring period, comfort conditions were assured with a sporadic daily energy consumption of 6 kWh – halogen heater – (0.16 kWh/m^2). With this consumption and under clear-sky conditions for about 80% of the time, the mean temperature in May was 21.9 °C, 8.8 °C above the outdoor mean (13.1 °C). During June, with clear sky, the indoor mean temperature was 20.6 °C, 11.2 °C above the outdoor mean (9.4 °C). It is evident that the heat input through the glazed balcony provided the necessary energy to keep comfort maximized by an adequate use of door–window connections between functional areas and closed balcony. In previous paragraphs we introduced some comments regarding overheating observed during summer, probably due to inadequate use of the balcony carpentry which remained closed during the summer monitoring period (unpublished information).

In Apartment 15, Block 126, facing S, indoor comfort conditions are observed, with a mean temperature during the monitoring period of 22.2 °C, 11.4 °C above the mean outdoors (10.8 °C). The owner has a 6000 kcal heater, which she switches off when she is absent from home and which is kept to low, according to her

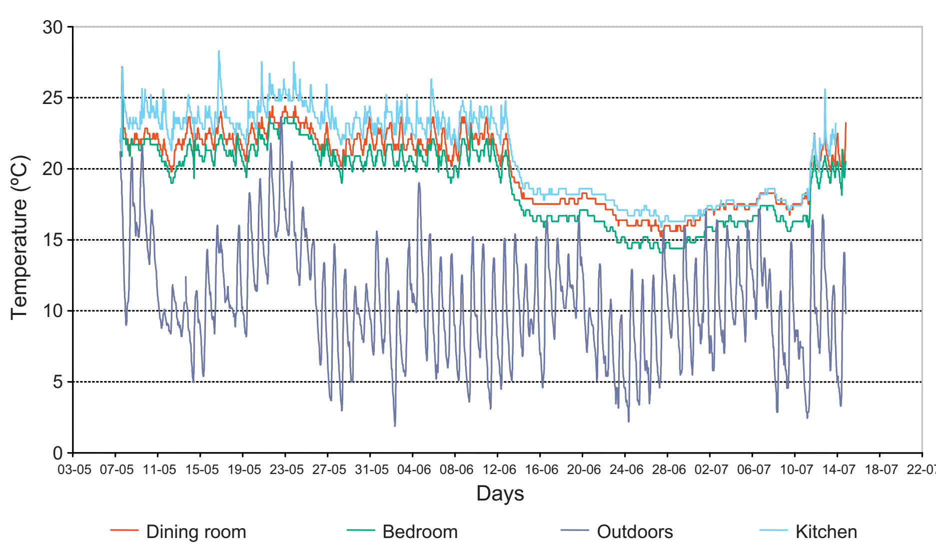

Fig. 17. Evolution of indoor temperature in Apartment 18 during May and June 2009.

Table 11
Natural gas consumption during 2009.

Block	Apartment	Annual natural gas consumption				Heating energy consumption (75% of May–June natural gas consumption)				
		m^3	Heating energy consumption (67% of annual natural gas consumption)			m^3	MJ/day		kWh/day	kWh/day/m^2
			m^3	kWh	kWh/y/m^2					
126	15	760	509.2	4961.6	95.4	121	90.7	80.6	22.5	0.43
	18	516	345.7	3368.7	87.9	110	82.5	66.6	18.5	0.48
	23	1060	710.2	6920.2	133.1	233	174.7	101.6	28.0	0.54
374	12							Halogen heater		0.16

answers in the questionnaire (in Fig. 15 a red line is observed in the dining-living room area). The heater was on for 6 h a day since 10 am, that is why the temperature rises above 27 °C for 24% of the monitoring period. The heating energy consumption during the monitored period was 90.7 m^3 (3179 MJ). Excluding the year 2009, the value is lower than the historical average (2001–2008) for the period May–June (165 m^3 – 5783 MJ) with a variability along the period of around 18%. The daily average auxiliary heating to reach comfort conditions was 2.3 m^3 (80.6 MJ – 22.5 kWh) (6 h × 3000 kcal, 7 h, 61 18,000 kcal; 1 m^3 natural gas = 8400 kcal). The daily heating energy consumption per useful area was 0.43 kWh/m^2.

In Apartment 18, second floor, same block but facing N, the diagram shows a very good performance. During the period of use, the heater (6000 kcal) was kept on to the low position for 6 h a day. The heating energy consumption during the monitored period was 110.0 m^3 (3855.5 MJ), similar to the average of the period 2001–2008 (115.8 m^3 – 3499 MJ). The daily average auxiliary heating was 1.9 m^3 (66.6 MJ – 18.5 kWh) (the apartment was occupied during 43 days) to reach a mean temperature of 22.2 °C. In this particular case, without the heater on and no input of indoor gains, the mean indoor temperature was 17 °C. The 5 °C difference between the occupied/unoccupied apartments was determined by indoor gains input, auxiliary heat and direct solar gain (Table 10). The daily heating energy consumption per useful area was 0.48 kWh/m^2.

In Apartment 23, second floor, same block, also facing South, indoor comfort conditions are observed, with a mean indoor temperature during the monitored period of 23.7 °C, 12.9 °C above the outdoor temperature (10.8 °C). The owner has two heaters in the dining-room and in the internal bedroom. The bedroom heater is on for about 6 h a day and the dining-room heater for about 4 h a day since 10 pm 29% of the time, the temperature rises above 27 °C. The heating energy consumption during the monitored period was 174.7 m^3 (6123 MJ) lower than the historical average (192 m^3 – 6730 MJ). The daily average auxiliary heat was 2.9 m^3 (101.6 MJ – 28 kWh) and 0.54 kWh/m^2. The results allow to infer the owner lived under comfort conditions during the period 2001–2008. The analysis of the results of the apartments' historical consumption of natural gas prior to the year 2009 allowed us to determine that the owner lived under conditions of comfort.

One of the objectives of the work proposed by the authors is to study proposals for thermal improvement. The main economic benefits of energy saving are realized in non-insulated houses, as the first centimetres of insulation are most effective and profitable [42]. According to the authors, the insulation of the roof appeared

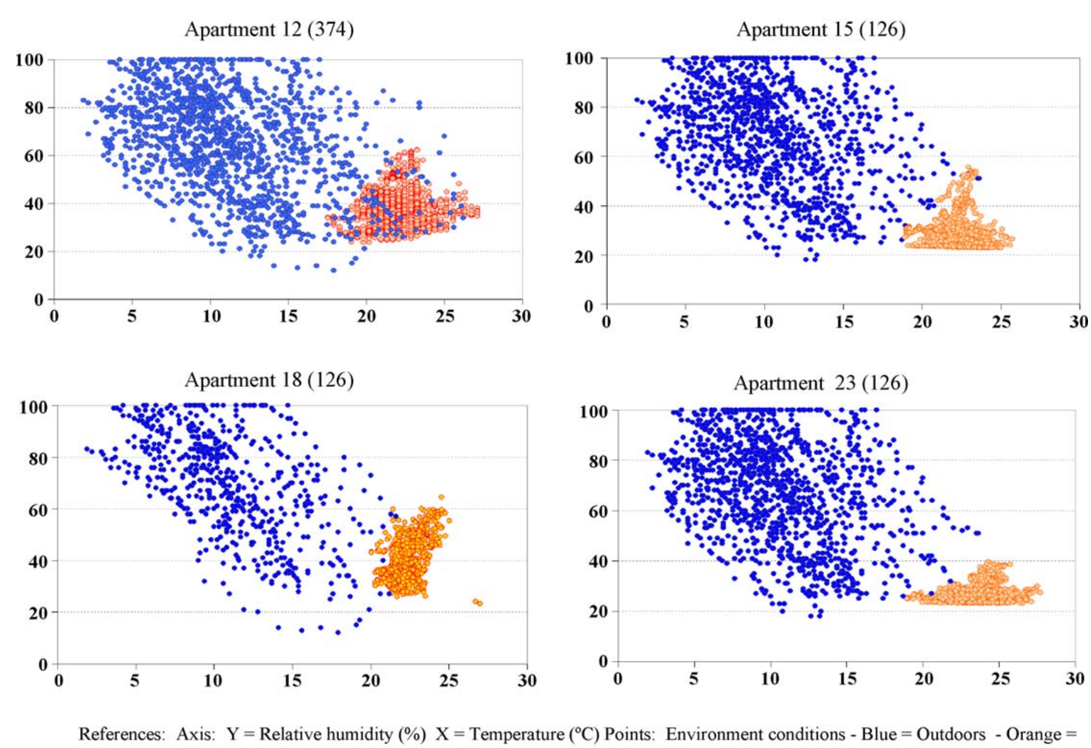

Fig. 18. Comfort diagram of each of the monitored apartments.

Table 12
Annual natural gas consumption in monitored and non-monitored apartments.

Apartment			Area (m^2)	Period 2001–2009					Observations
Block 126	Number	Level		Annual natural gas consumption (m^3) (see Table 3)		Annual heating natural gas consumption 67% of [1]		Annual heating/m^2 (kWh)	
				Average [1]	CV	m^3	kWh		
Monitored apartments	15	First floor	52.0	906.3	16.6	607.2	5916.8	113.8	Facing South
	18	Second floor	38.3	712.7	15.0	477.5	4652.8	121.5	Facing North
	23		52.0	1173.4	11.1	786.2	7660.5	147.3	Facing South
Facing South	3	Ground floor	50.8	1123.3	4.8	752.4	7333.4	144.4	Shaded
	9	First floor	50.2	634.5	12.7	424.8	4142.3	82.5	
	13		50.8	878.5	9.3	588.6	5735.3	112.9	
	17	Second floor	52.0	1307.2	5.4	875.8	8534.0	164.1	
	19		52.0	879.7	9.0	589.4	5743.1	110.4	Shaded
	21		52.0	1227.0	7.0	822.0	8010.4	154.0	
Facing North	6	Ground floor	65.8	921.8	7.2	617.0	6018.0	91.5	
	10	First floor	38.3	450.8	10.2	302.0	2943.0	76.8	
	12		38.3	619.0	10.9	415.0	4041.1	105.5	
	20	Second floor	38.3	895.6	8.9	600.0	5846.9	152.7	

to be the most effective measure, both energy-wise and economical, since the roof represents a large part of the building envelope with a high impact on the load demand (in winter and summer) but low investment costs compared with other measures.

In our case study, a roof with 7.5 cm insulation thickness would lower the K value (0.50 W/m^2 °C) which lies between IRAM Norm 11605 [37] levels A and B. The wall thermal transmittance with 5 cm insulation thickness would lower the K value 1.84–0.50 W/m^2 °C which lies between levels A and B of the above mentioned Norm. The cost per square meter of thermal improvement of the roof and the wall (materials and workmanship) is around 28 and 24 US dollar, respectively (1 US dollar = $3.5). The improvement would reduce the Volumetric Loss Coefficient (G) and also heating energy consumption by 17% keeping an indoor temperature of 18 °C. While insulation of the façade is more expensive, the thermal improvement with 5 cm thickness increases 12% more energy savings.

8. Results extrapolation to the rest of Block 126

Previous works [40,41] showed that the historical annual natural gas consumption per block presented a variability among the eight buildings of 4.17% (average consumption = 21,359.3 m^3 or 748,651 MJ). Considering the annual average consumption for each block, by apartment and by the level of location, variability among buildings was 12.2%, 16.6% and 11.1% for the ground, first and second floors, respectively.

On the basis of results obtained after monitoring some apartments and from the analysis of those apartments' energy consumption patterns, we studied the possibility of extrapolating results to other apartments with the aim of estimating whether the non-monitored apartments reached comfort conditions. Thus, we considered in the first place those apartments within Block 126 that showed little variability in their annual gas consumption during the period 2001–2008: 3, 9, 13, 17, 19, 21 (south) and 6, 10, 12, 20 (north) (Table 12).

A first approximation allows us to observe that:

- Apartments facing north, on average, consume 14% less gas than those facing south.
- Apartments 10 and 12, facing north (first floor, less surface exposed outdoors) consume 55 and 13% less than Apartment 18, respectively. Apartment 18 (monitored) on the second floor presents a roof without thermal insulation. It is worthy to note that it has a 6000 kcal heater while Apartments 10 and 12 have 2500 kcal ones. All the dwellers answered that indoor temperature is comfortable during winter and that they open completely their roller curtains between 8 and 12 am and partially between 12am and 6 pm to let the sun in. They associate comfort with solar light availability.
- Apartment 6 on the ground floor consumes 32% less than 18, whereas 20, on the second floor consumes 20% more.
- Apartments 9 and 13, facing south, on the first floor and occupying a central position, consume annually between 45 and 8% less gas respectively than Apartment 15 (monitored), a foreseeable situation due to less energy loss.
- Apartments 17 (towards the SW end) and 21 (towards the S), in the centre, both on the second floor and surrounded by perennial trees that provide extra shade, consume more gas. Apartment 19, in the centre and having less losses, consumes 30% less gas than 23 (monitored).
- Apartment 3 on the ground floor and towards the centre of the building shows a higher level of consumption than that of the first floor, Apartment 15, towards the SE end (120.1 kWh/y/m^2). It may be inferred that even when there might be heat transfer through the mezzanine, and losses through the floor, the consumed volume would assure thermal comfort.

9. Conclusions

This work, through monitoring and feedback from dwellers, enabled us:

(a) To evaluate the thermal performance of apartments in multi-family buildings in block and their conditions of comfort.
(b) To complete the energy analysis done in a previous work for the period 2001–2006.
(c) To explore potential energy saving and feasible interventions to reduce energy consumption.
(d) To relate the monitoring results obtained during 2009 to heating natural gas consumption in previous years.

Results showed that Apartment 12, facing north, with its only bedroom facing NE and its balcony closed with carpentry and

transparent glass, kept comfort conditions with the aid of a halogen heater switched on for 6 h per day, between 9 pm and 2 am (0.16 kWh/m^2/day). The closed balcony appears to be an adequate bioclimatic design strategy for the region under study. An improvement in heat transfer by convection increasing air velocity could optimize the use of this space as passive use of solar energy. The summer behaviour showed overheating (windows remained closed). From a technology perspective, it is not advisable since the balcony's parapets and the balcony itself were not structurally designed and conceived to bear additional weight. On the SE, Apartment 15, on the first floor of the block, kept comfort conditions with lower gas consumption (0.43 kWh/day/m^2) than that of Apartment 23, same surface but occupying the second (last) floor (0.54 kWh/day/m^2). This last one consumed more gas than number 18 (0.48 kWh/day/m^2), also on the second floor but facing north and located in the centre with only one bedroom facing NE. The heater was switched off when Apartments 15 and 18 were not inhabited. This constitutes important information because the rational use of energy is not common in our region.

Results showed, on the one hand, the influence of orientation and location of each apartment on the different levels of the blocks, and on the other, that daily gas consumption during the monitoring period in 2009 did not deviate from the mean value for the period 2001–2008. It can be inferred that in all previous years the users lived always under conditions of comfort. It may also be inferred that, even though only three apartments have been monitored out of a total of 24, results may be extrapolated to 50% of the building – apartments are occupied by their owners, living in the building for a period of 20–35 years. Gas consumption and roller curtains opening in the apartments facing north assure indoor comfort.

The unfavourable energy situation of the apartments located on the second (top) floor is also an evident result that emerges from our analysis, situation that shows that the roof should be insulated in accordance with recommendations by IRAM Norm 11605, which considers three levels A, B and C. For the region under study and for winter, the IRAM Norm recommends an acceptable maximum K value of 0.29, 0.74 and 1.00 W/m^2 K for levels A, B and C, respectively. Adding thermal insulation would allow to reduce not only the heating values but also the cooling ones, since almost all apartments on the second floor have a mechanical cooling system. It is also possible to extrapolate results from Block 126 to the other 7 blocks, since consumption in and among them shows little variability [41].

The heating annual energy consumption in the monitored apartments (average during 2001–2009 = 121.3 kWh/m^2/y) is lower than that in multi-family buildings studied in Italy (higher annual degree-days) with a value of 200 kWh/m^2/y for old constructions without any significant variations until the 70s [43]. In the city of Santa Rosa, a sample of non-insulated multi-family apartments in high-rise buildings facing North (azimuth = 180°) and South respectively consumed, under comfort conditions, an average heating energy of 75.4 and 84.5 kWh/m^2 (2001–2009). The apartments have, on the one hand, less exposure to the outside environment, and on the other, individual water heating systems. The owners generally set the indoor temperature around 21 °C (unpublished data). The potential of thermal improvements could reduce emissions in the next years.

The aim of this work had been to analyze the potential and possible interventions to keep comfort conditions and save energy. According to our estimates these interventions are feasible. Experimental low-energy buildings have been designed, constructed and tested in the study area achieving significant energy savings and reducing emissions of CO_2 [44]. According to [42] the main economic benefits of energy saving are realized in non-insulated houses, as the first centimetres of insulation are most effective and profitable.

On the basis of the results of this work, the next step would be to promote the incorporation of the different recommendations included in the IRAM Norms regarding environmental conditioning of buildings to the Construction Code of the city of Santa Rosa, in its Chapter 5. In the case of new buildings, it is not only desirable but mostly a compelling matter to recommend good orientation practices and an energy-efficient envelope design in accordance with enforced national regulations. From a theoretical perspective, the psychrometric diagram for the city's climate showed that it is possible to reach comfort during an important number of hours in winter by adequately using solar energy.

Given the many possibilities to substantially reduce buildings' energy requirements, the potential saving of energy efficiency in the building sector would greatly contribute to a society-wide reduction of energy consumption. The implications of such potential reduction should not be underestimated, as the scale of energy efficiency in buildings is large enough to influence security policy, climate preservation and public health on a national and global scale [10].

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